The Polarized Gas JET Target and Polarimetry at RHIC

Impact on Spin Physics

Polarimeters used in the complex

The Polarimetric Process

The p-Carbon CNI polarimeters

accomplishments AGS / RHIC

systematics and upgrades

The polarized gas JET target

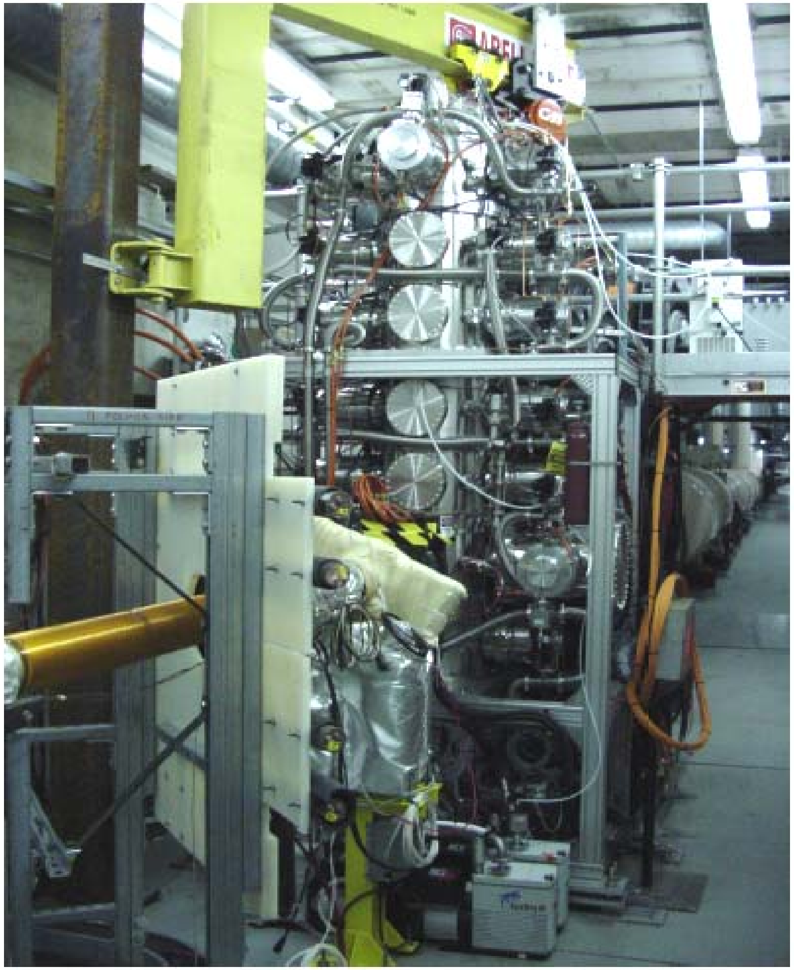
construction, status

“online” results from 2004

future plans

The BNL scientific contribution

Publications



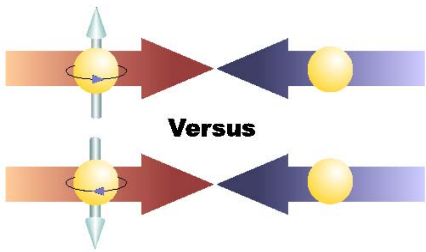
DoE RHIC S&T Review
June 30, 2004

Alessandro Bravar

BROOKHAVEN NATIONAL LABORATORY

Polarimetry : Impact on Spin Physics

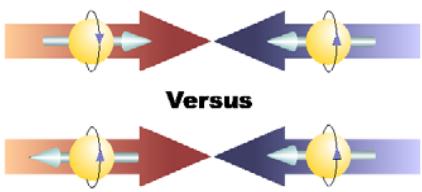
Single Spin Asymmetries



Physics Asymmetries

$$A_N = \frac{1}{P_B}\left(\frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}\right)$$

Double Spin Asymmetries



$$A_{LL} = \frac{1}{P_B^{\,2}}\left(\frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}}\right) \Rightarrow \boxed{\Delta G}$$

measurements

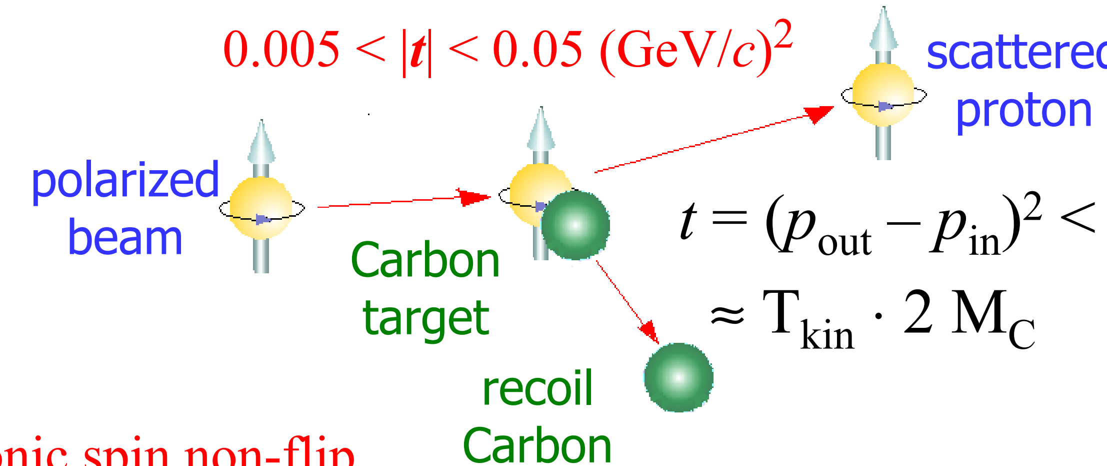
- measured spin asymmetries normalized by P_B to extract Physics Spin Observables
- RHIC Spin Program requires $\Delta P_{beam} / P_{beam} \sim 0.05$
- normalization $\Rightarrow$ scale uncertainty
- polarimetric process with large σ and known A_N
  - *pC* elastic scattering in CNI region
  - fast measurements
  - requires absolute calibration $\rightarrow$ polarized gas jet target

Elastic pC → pC scattering at low t

$$P_B = -\frac{1}{A_N} \cdot \frac{N_{left} - N_{right}}{N_{left} + N_{right}}$$

recoil

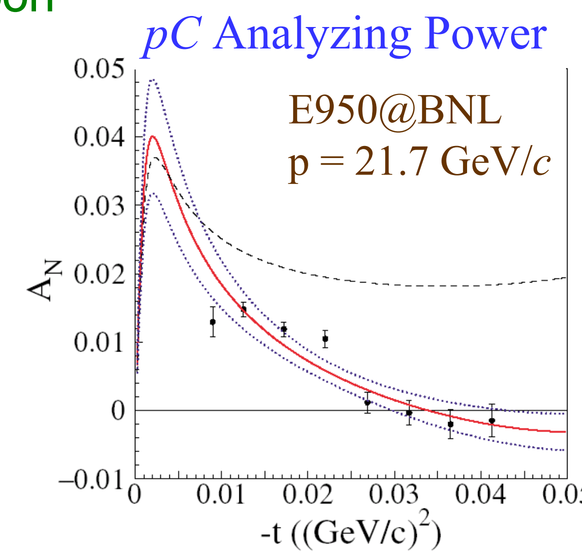
$0.005 < |t| < 0.05\ (\mathrm{GeV}/c)^2$



$$t = (p_{out} - p_{in})^2 < 0$$
$$\approx T_{kin} \cdot 2\, M_C$$

1. A_N from interference of hadronic spin non-flip and ElectroMagnetic spin flip amplitudes
   can be traced back to Schwinger (1948)
   ⇒ spin dependence of interaction
   ⇒ hadronic spin flip (spin-coupling of Pomeron)

2. Polarimetry
   – almost “calculable”, requires “calibration” to 5%
   – small $A_N \sim 1 - 2$ % ⇒ requires large statistics > 10^7
   – large cross section
   – weak beam momentum dependence (p > 20 GeV/*c*) ?
   – absolute “calibration”: elastic *pp* scattering with polarized gas-jet target



PHYSICAL REVIEW VOLUME 73, NUMBER 4 FEBRUARY 15, 1948

On the Polarization of Fast Neutrons

JULIAN SCHWINGER
Harvard University, Cambridge, Massachusetts

(Received January 8, 1948)

ALTHOUGH the production of polarized thermal neutrons has long been an accomplished fact, no such success has been forthcoming with fast neutrons. Only one method for the polarization of fast neutrons has thus far been suggested,[1] of which the essential mechanism is the large, effective nuclear spin-orbit interaction present when neutrons are resonance scattered by helium and similar nuclei. It is the purpose of this note to suggest a second mechanism for polarizing fast neutrons—the spin-orbit interaction arising from the motion of the neutron magnetic moment in the nuclear Coulomb field. Despite the apparent small magnitude of this interaction, the long-range nature of the Coulomb field is such that the use of small scattering angles will produce almost complete polarization under ideal conditions. A closely related phenomenon produced by this electromagnetic interaction is an additional scattering of unpolarized neutrons which increases rapidly with decreasing

where $k=p/\hbar$ is the neutron wave number. Hence, the unscreened Coulomb field of a point nucleus will be effective for scattering in the angular range:

$$1/ka \ll 2\sin\vartheta/2 \ll 1/kR. \tag{3}$$

If the nuclear radius and atomic screening radius are taken to be

$$R=1.5\cdot 10^{-13}A^{\frac{1}{3}}\text{ cm} \quad \text{and} \quad a=0.53\cdot 10^{-8}Z^{-\frac{1}{3}}\text{ cm},$$

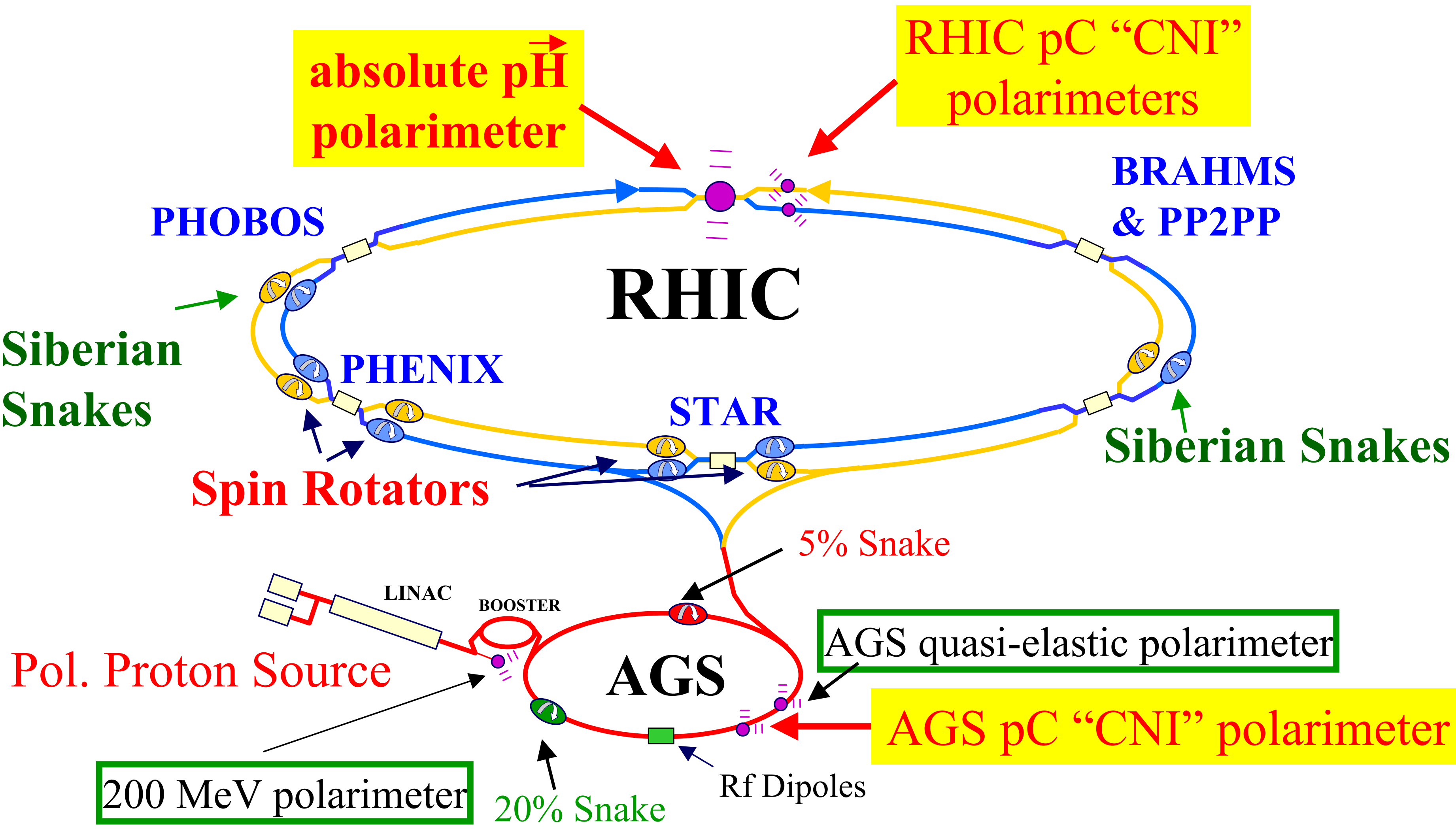
the angle restrictions for a 1-Mev neutron scattered in Pb, for example, are

$$4\cdot 10^{-4} \ll 2\sin\vartheta/2 \ll \tfrac{1}{2}. \tag{4}$$

The electromagnetic scattering of a neutron under these conditions can be calculated with the plane wave Born approximation, for the nuclear scattered wave is negligible compared with the incident wave at the significant scattering distances. We denote the incident plane wave by

$$\psi_0 = e^{i\mathbf{k}_0\cdot\mathbf{r}}\chi, \tag{5}$$

RHIC pp accelerator complex & Polarimeters



Polarimeters in the C-AD complex

- LINAC 200 MeV
  - inclusive production proton from p Carbon interactions
    - 50% analyzing power, Fast a 2% in about 1 min.
  - pd elastic scattering
    - slow, used to calibrate the above polarimeter
- Booster
  - none, however measure in AGS just after injection
- AGS
  - pp quasi-elastic scattering on HydroCarbon and Carbon targets
    - 3-5% analyzing power, good to $G\gamma \sim 12$
    - slow at higher energies, 10% measurement in ½ hour
  - p Carbon CNI polarimeter
    - 1-2% analyzing power at 24 GeV, fast 5% in 5 min.
    - analyzing power known to 30% at 22 GeV
    - ramp measurements
- RHIC
  - p Carbon CNI polarimeters in Blue and Yellow beams
    - analyzing power known at 22 GeV to 30%
    - fast, a 2% measurement in about 30 sec.
    - ramp measurements
    - polarization profile measurements
    - spin tune measurements

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Some history and future plans

- FY 1998
  - E950 in AGS: demonstrated feasibility of a pC CNI polarimeter
- FY 2000
  - 1^{st} pC CNI polarimeter in RHIC (partial, Blue Ring)
- FY 2001-02
  - pC CNI polarimeters for both RHIC RINGS
- FY 2003
  - pC CNI polarimeter also for AGS
- FY 2004
  - Jet Target (Blue beam only)
  - Doubled acceptance of RHIC pC polarimeters
  - Upgraded AGS pC polarimeter
    - Better understanding of systematics, eliminated beam wake fields pickups
- FY 2005
  - Jet Target for both RHIC beams
  - Upgrade RHIC pC polarimeter (systematics, beam wake fields)
- FY 2006
  - All developments should be completed

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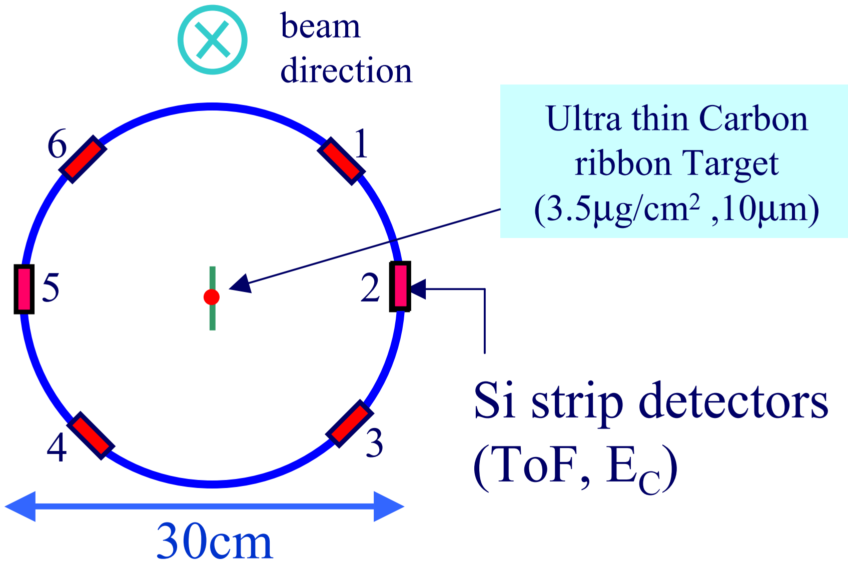
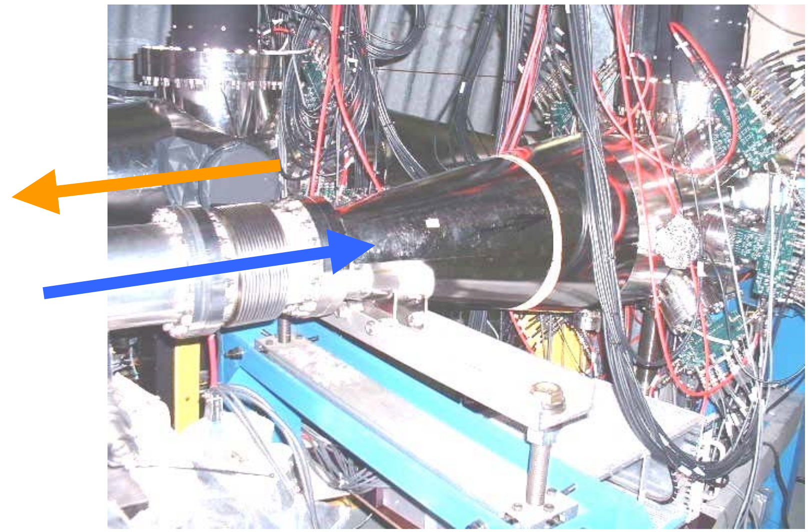
RHIC pC Polarimeters



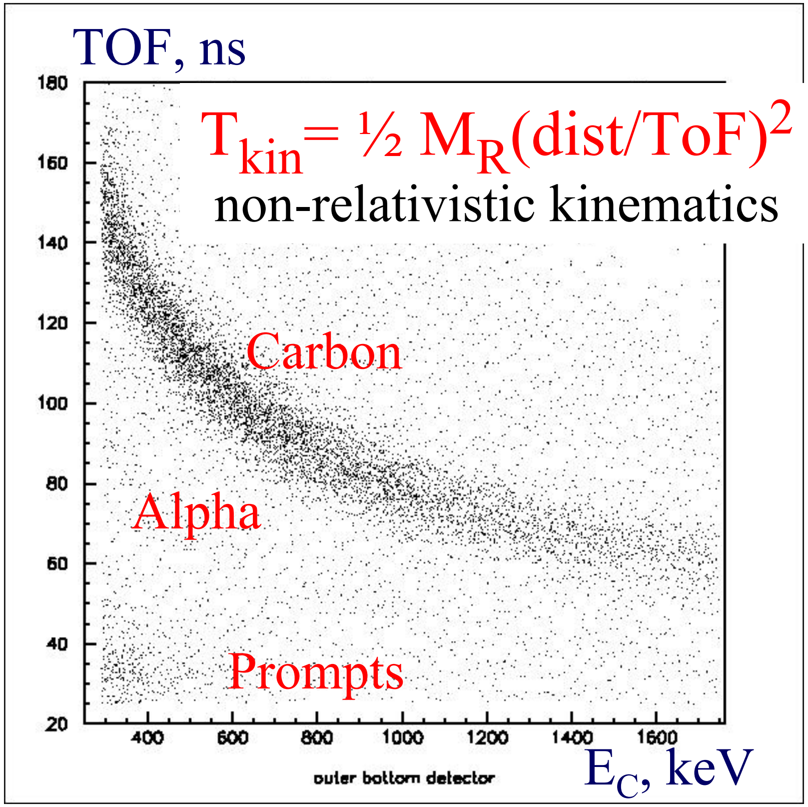
RHIC × 2 rings

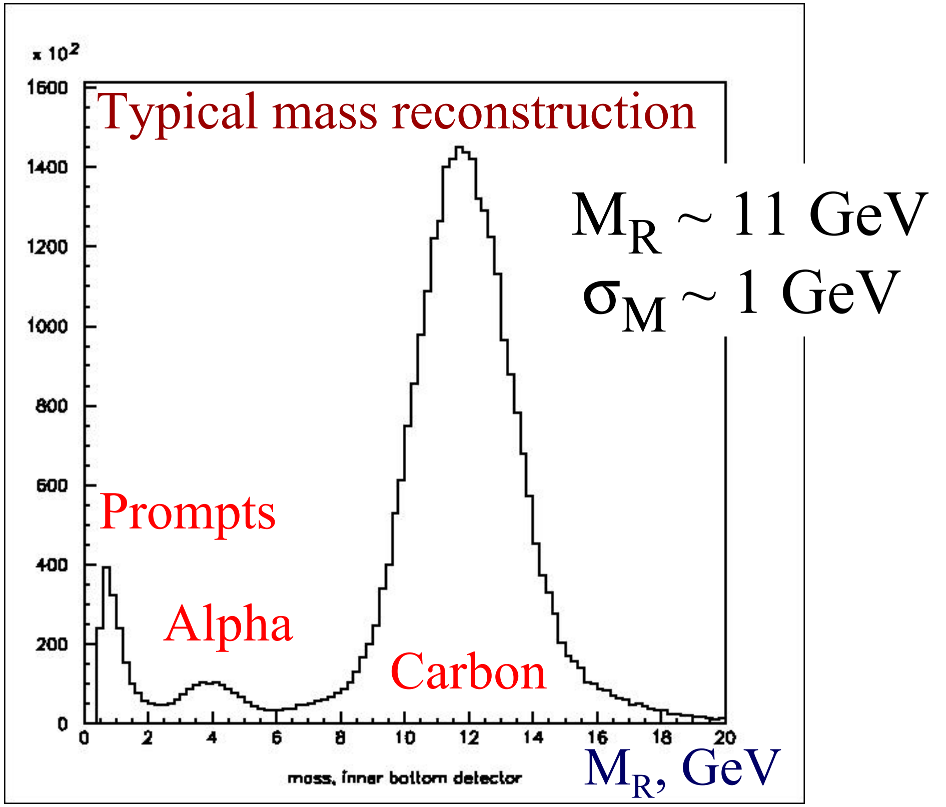
inside RHIC ring @IP12



- 2 × 72 channels read out with Wave Form Digitizers
- very large statistics per measurement (~ 20×10^6 events) → detailed analysis
  - bunch by bunch analysis
  - channel by channel (each channel is an “independent polarimeter”)
  - 45° detectors: sensitive to vertical and radial components of $\vec{P}_{beam}$
    → unphysical asymmetries

Performance





- Very clean data
- Good separation of recoil carbon from α ($C^* \rightarrow \alpha + X$) and prompts

  very low background, may allow going to very high $|t|$ values
- Low χ^2 of sequential measurements – stable operation

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pC Polarimeter systematic issues

- calibration only at 22 GeV to $\pm$ 30%
  assume: A_N (E950) = A_N (24.3 GeV) = A_N (100 GeV)
  soon will have absolute calibration from JET target
- observed systematic error of relative measurements to $\Delta P = \pm$ 3%
- during '04 run very stable operation
  - effective A_N for each measurement very stable and around 1.5 %
  - very low backgrounds
- energy scale
  - dead layer energy correction
    small change $\rightarrow$ small change in $|t|$ $\rightarrow$ significant change in $A_N(t)$
  - however radiation damage not an issue
- beam wake fields induced pickups
  - solved in AGS, will be implemented in RHIC for '05 run
- beam polarization profile
  - the pC CNI polarimeter sees only the beam center while
    the experiments & JET integrate over the whole profile

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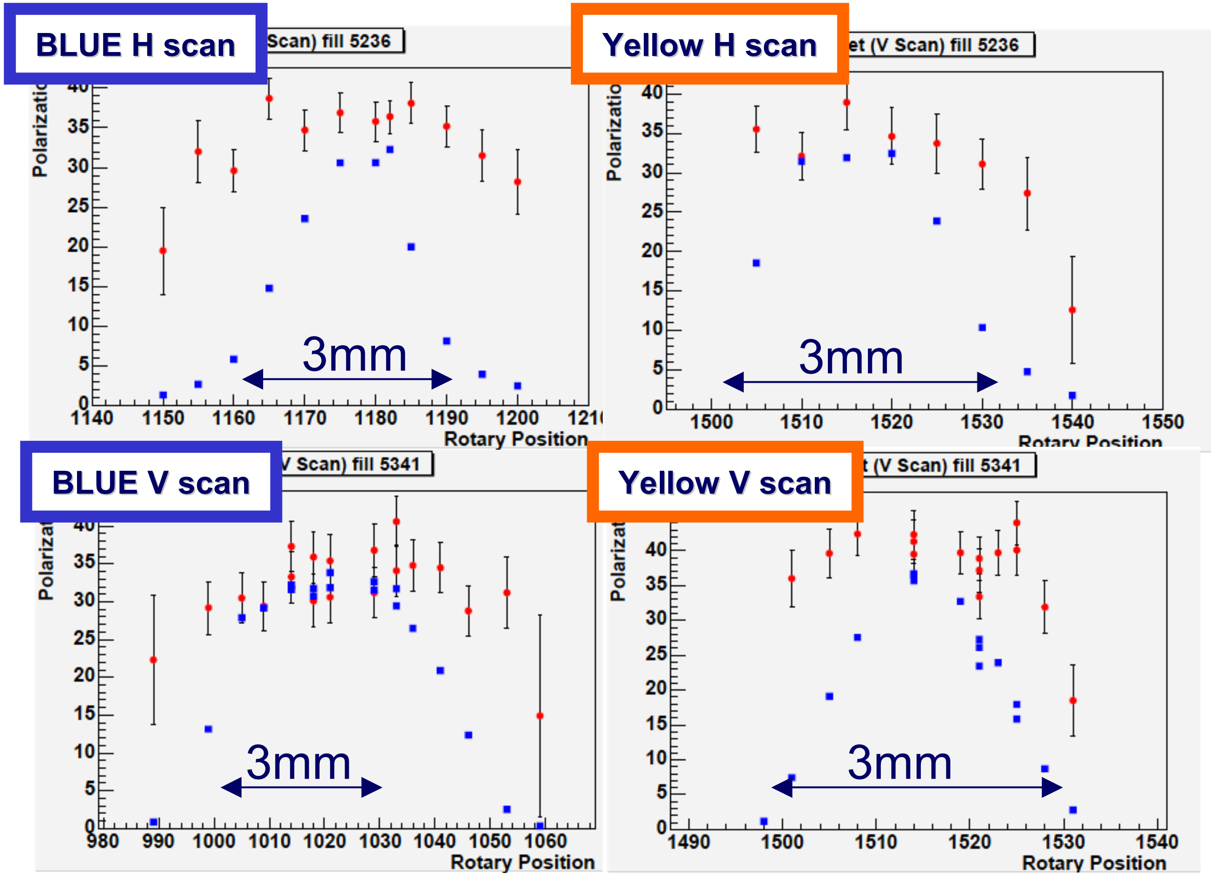
RHIC polarization profile



H Scan --horizontal scan with vertical target

V Scan – vertical scan with horizontal target

large polarization profile in vertical direction (small profile in horizontal)

observed position dependent fluctuation in polarization measurements

an issue for "calibration": the JET integrates over the full beam profile

the pC CNI polarimeter measures the beam center

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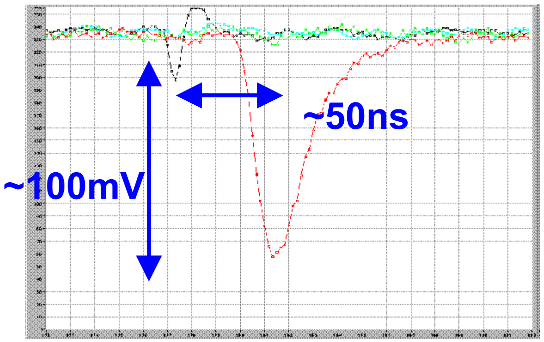
DAQ and WFD

Wave Form Digitizer = peak sensing ADC, CFD, …

common to the *pC* and JET DAQ system



ADC
3×140 MHz

↓

FPGA

↓

onboard memory → DAQ PC

synchronized to accelerator clocks

bunch X-ing $\Rightarrow$ "start" TDC

"online" analysis of waveform performed beteween consecutive bunch X-ing

$\Rightarrow$ PH, tot Q, t.o.f

Δt ~ 2 ns

ΔE < 50 keV

20×10^6 events in 20 seconds $\Rightarrow$ deadtimeless DAQ system

can accept, analyze, and store 1 event / each bunch $\times$-ing

The Road to P_{beam} with the JET target

Requires several independent measurements

0 JET target polarization P_{target} (Breit-Rabi polarimeter)

1 A_N for elastic pp in CNI region: $A_N = - 1 / P_{target}\, \varepsilon_N'$

2 $P_{beam} = 1 / A_N\, \varepsilon_N''$

1 & 2 can be combined in a single measurement: $P_{beam} / P_{target} = - \varepsilon_N' / \varepsilon_N''$

"self calibration" works for elastic scattering only

3 CALIBRATION: A_N^{pC} for pC CNI polarimeter in covered kinematical range:

$A_N^{pC} = 1 / P_{beam}\, \varepsilon_N'''$

(1 +) 2 + 3 measured simultaneously with several insertions of carbon target

4 BEAM POLARIZATION: $P_{beam} = 1 / A_N^{pC}\, \varepsilon_N''''$ to experiments

at each step pick-up some measurement errors:

$$\frac{\Delta P_{beam}}{P_{beam}} = \left(\frac{\Delta P_{target}}{P_{target}}\right) \underset{\text{transfer}}{\oplus} \left(\frac{\Delta\varepsilon}{\varepsilon}\right)_{pp} \underset{\text{calibration}}{\oplus} \left(\frac{\Delta A_N}{A_N}\right)_{pC} \underset{\text{measurement}}{\oplus} \left(\frac{\Delta\varepsilon}{\varepsilon}\right)_{pC} \leq 6\%$$

expected precision

The Polarized Jet target for RHIC-Timeline

- The design and simulations started in early 2002
- A cost estimate of $1.45 M was arrived at in June 2002
- The sextupole magnets (a long lead item) order was placed in July 2002
- A DOE review (design, cost, and schedule) was carried out in Nov 2002
- First steel was cut in January 2003
- The Atomic Beam stage saw first beam in May 2003. Record intensity June 2003
- The RF transitions and the Breit-Rabi polarimeter were installed in Aug 2003
- RF transition efficiency (~100%) and polarization (~96%) measured in Sept 2003
- Conventional construction in the IR and service building completed Sept 2003
- The Jet was installed in RHIC for a successful dress rehearsal in Oct-Nov 2003
- Prototype detectors and electronics tested in the JET January 2004
- The silicon detectors and electronics were installed in March 2004
- The jet was reinstalled in RHIC in April 2004 and took data with beam

Overall, the jet came in on time and within the allotted budget

The Atomic H Beam Source

Hyperfine state
(1), (2), (3), (4)

↓

(1), (2)

↓

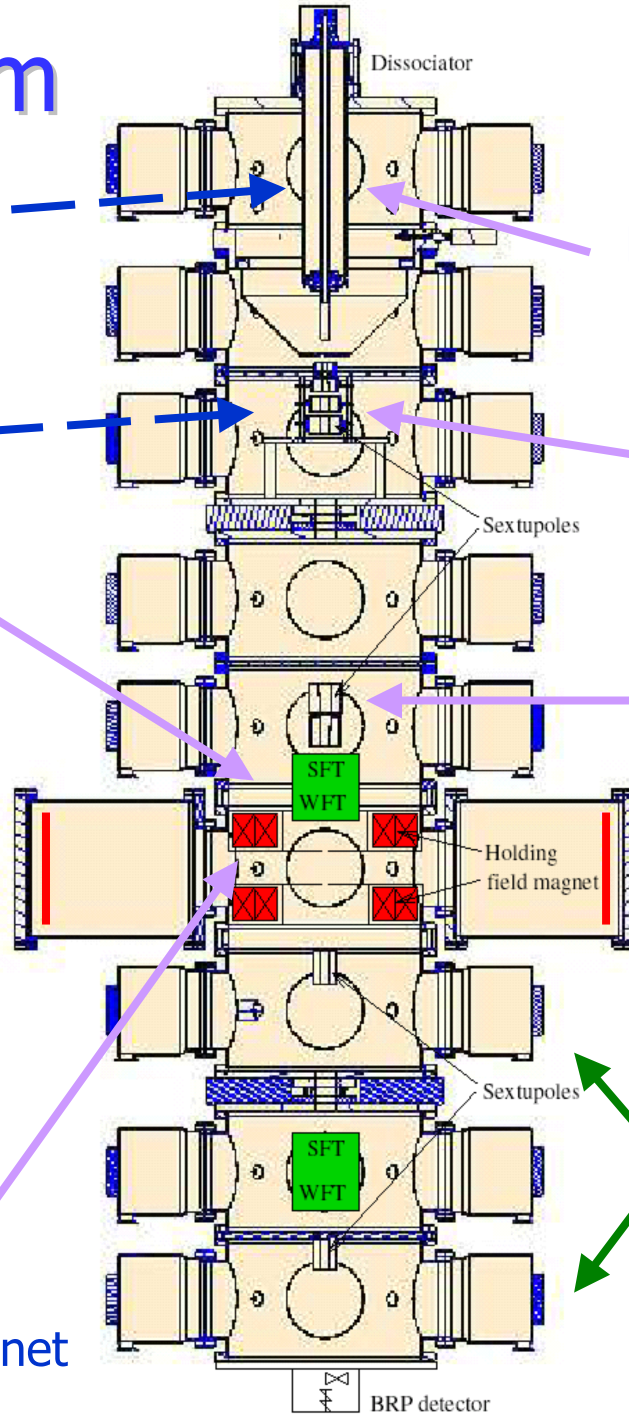
Pz+ : (1), (4) (SFT ON (2)→(4))

Pz- : (2), (3) (WFT ON (1)→(3))

Pz0: (1), (2), (3), (4)

(SFT & WFT ON)

record beam intensity
100% eff. RF transitions
focusing high intensity
B-R polarimeter



H_2 dissociator

separation magnets (sextupoles)

RF transitions

focusing magnets (sextupoles)

recoil detectors

Breit-Rabi polarimeter

holding field magnet

Operation parameters

- The Jet ran with an average intensity of 1×10^{17} atoms / sec
- The jet thickness of ~ 10^{12} atoms/cm^2 record intensity
  (no discernable effect on the beam or lifetime)
- Jet polarization (-95.9 % and +95.7 % respectively)
  This to be scaled down due to a 3% H_2 background
- No observed depolarization from beam wake fields at 56 bunches
- The jet vacuum was at 4×10^{-9} Torr / jet off &
  2×10^{-8} Torr / jet on
- The beam line vacuum was at 6×10^{-9} Torr at 1 meter away
- Data taken under different RHIC beam conditions:
  Blue beam only, Blue and Yellow anticogged (dedicated), Blue and Yellow
  very small background increase $\rightarrow$ can run "parasitically"

JET target polarization

Target polarization cycle

+ / - / 0 ~ 500 / 500 / 50 sec

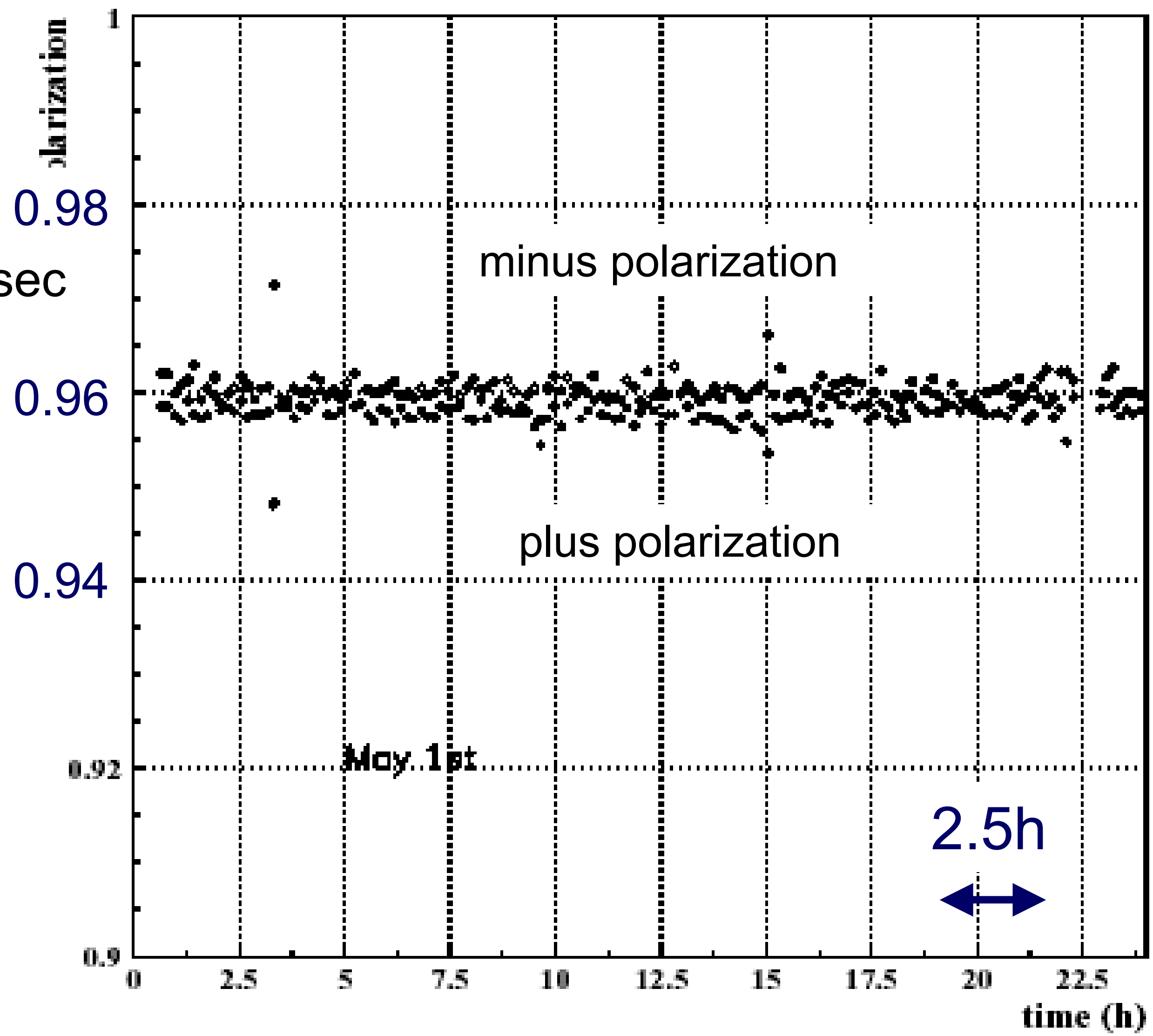
(600 /600 / 60 cycle

1 cycle = 0.83 sec)

polarization to be scaled down due to a ~3% H_2 background:

P_{target} ~ 93 % +2% -3%

(current understanding)



Recoil Si spectrometer

$A_N^{beam}(t) = -A_N^{target}(t)$

for elastic scattering only!

$P_{beam} = - P_{target} \cdot \varepsilon_N^{beam} / \varepsilon_N^{target}$

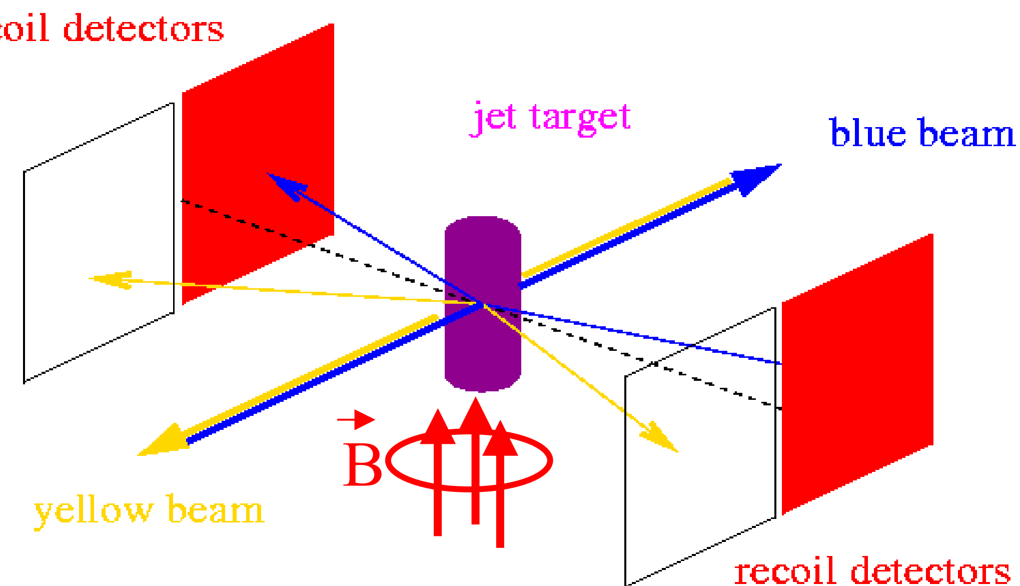
6 Si detectors covering blue beam

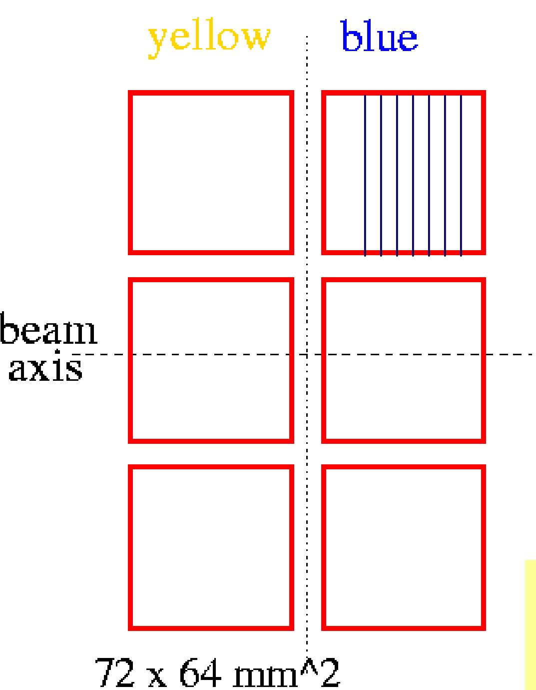
MEASURE

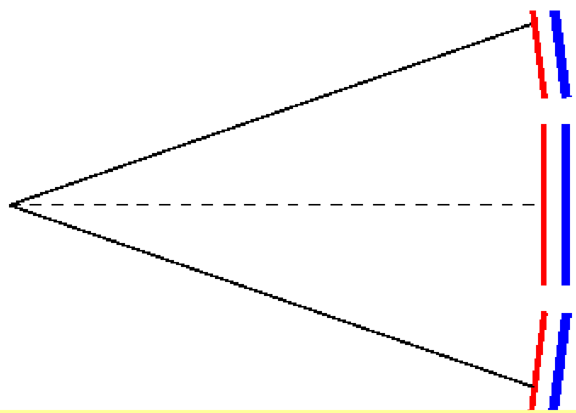
- energy (res. < 50 keV)
- time of flight (res. < 2 ns)
- scattering angle (res. ~ 5 mrad)

of recoil protons from

pp → *pp* elastic scattering







HAVE "design" azimuthal coverage

one Si layer only
⇒ smaller energy range
⇒ reduced bckgrnd rejection power

Si detectors from BNL Inst. and Hamamatsu
Electronics developed by BNL Inst. and Physics

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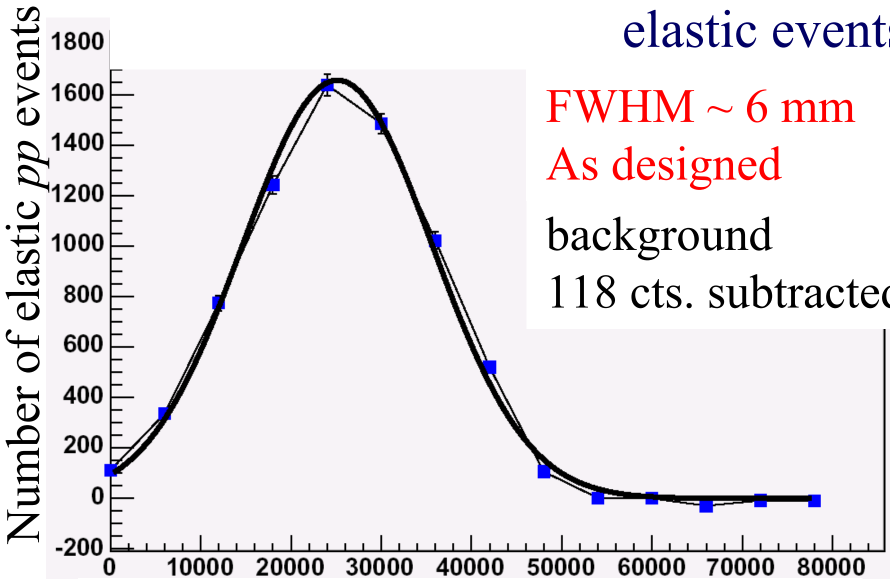
pp elastic data collected

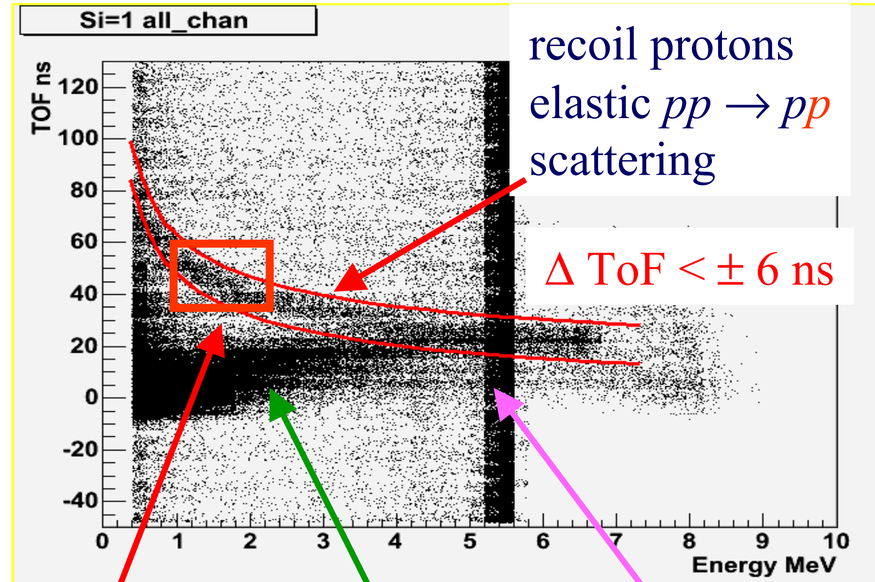
ToF vs E_{REC} correlation

$T_{kin} = ½\, M_R (\mathrm{dist}/\mathrm{ToF})^2$

JET Profile: measured selecting *pp* elastic events



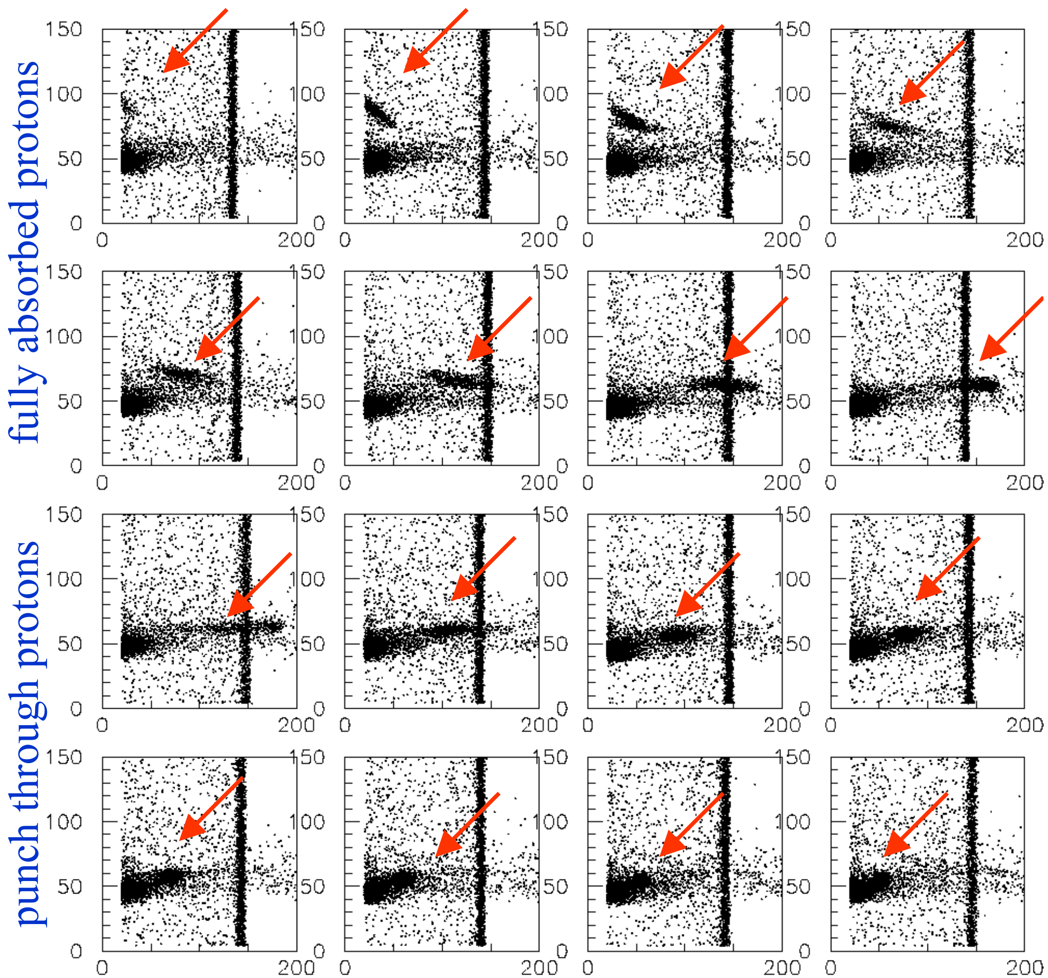
Hor. pos. of Jet 10000 cts. = 2.5 mm



- recoil protons unambiguously identified !
- 100 GeV ~ 700,000 events at the peak of A_N ~ 100 hours
  (~ 2×10^6 total useful *pp* elastic events)
- 24 GeV ~ 120,000 events at the peak of A_N ~ 17 hours
  (~ 4×10^5 total useful *pp* elastic events)

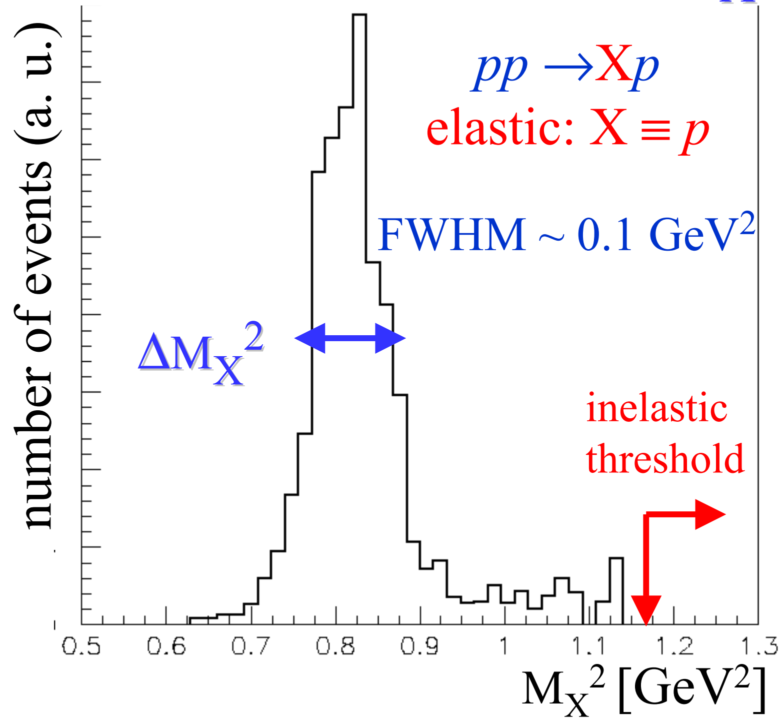
Energy - Position correlations

$T_{kin} \propto \theta^2$ (i.e. position^2)



TDC vs ADC individual channels

reconstructed missing mass M_X^2



pp elastic events clearly identified !

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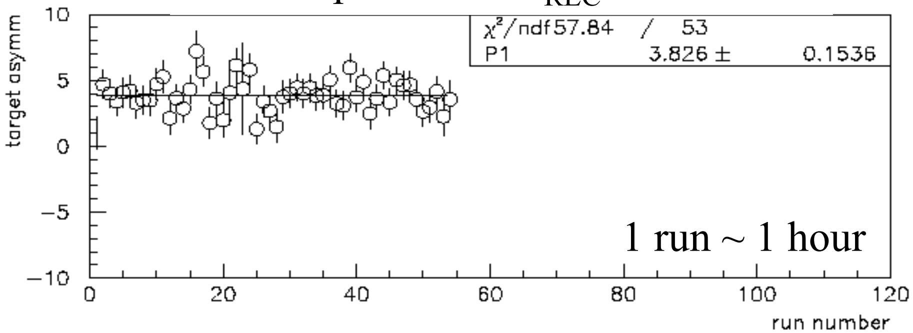
“ONLINE” measured asymmetries & Results

ONLINE ≡ statistical errors only
no background corrections
no dead layer corrections
no systematic studies
no false asymmetries studies
no run selection

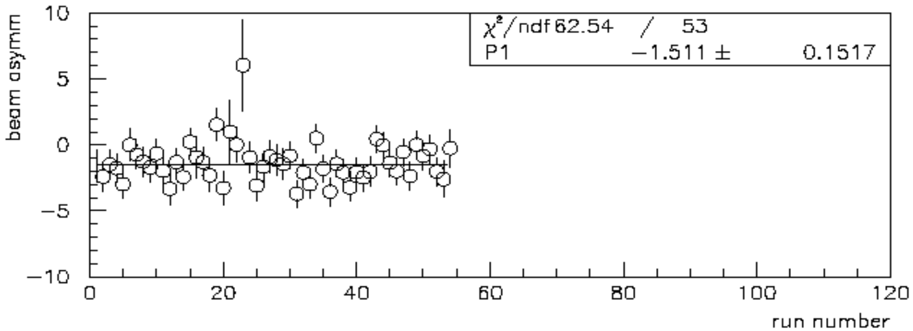
data divided into 3 *p* energy energy bins

an example: 750 < E_{REC} < 1750 keV

“Target”: average over beam polarization



“Beam”: average over target polarization



blue beam with alternating bunch polarizations: ↑↓ ↑↓ ↑↓ …

good uniformity from run to run (stable JET polarization)
JET polarization reversed each ~ 5 min.

$$P_{beam} = -P_{target} \cdot \frac{\varepsilon_{beam}}{\varepsilon_{target}}$$

P_{beam} = 36.9 % ± 1.9 %

$\langle P_{beam}\ (pC\ \mathrm{CNI}) \rangle$ = 38.1 %

No major surprises ?

(statistical errors only !)

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What next for JET in 2005

- Complete A_N analysis for the 100 and 24 GeV data.
- Complete the *pC* polarimeter analysis and systematics
- Measure A_N for the *pC* Blue beam polarimeter ("calibrate")

- Install silicon detectors also for the Yellow beam
- Slower shaping amplifiers
- Extend $|t|$ range $\Rightarrow$ increase F.o.M. of JET polarimeter

- Improve the jet dissociator performance (clogging)
- Add shutters to turn off the α sources for data taking
- Improve the jet H_2 and H_2O background measurement
- NEG coating to minimize electron clouds

Prepare for the next run

The Collaboration: JET and pC polarimeters

BNL Physics: A. Bravar, G. Bunce, R. Gill

BNL C-AD: H. Huang, Y. Makdisi,
A. Nass, A. Zelenski

BNL Instrumentation: Z. Li, S. Rescia

RBRC: O. Jinnouchi, H. Okada

Univ. of Wisconsin: W. Haeberli, T. Wise

ITEP- Moscow: I. Alekseev, D. Svirida

UCLA- G Igo, C. Whitten, J. Woods

IUCF: W. Lozowski, E. Stephenson

Kyoto University: N. Saito

Rikkyo University: K. Kurita

ANL: H. Spinka, D. Underwood

Yale: S. Dhawan

Summary

- the polarimeters work reliably
- steady progress in understanding and addressing systematic issues
- fast measurements of P_{beam} in few min. (AGS) / 30 sec. (RHIC)
- several hardware issues solved since last year

  (it is clear what needs to be improved and how …)
- polarized gas JET target worked beautifully

  (target, recoil spectrometer, …)
- acquired enough statistics for a first measurement of
  P_{beam} to better than 10% @ 100 GeV
  & 15% @ 24 GeV
- based on present understanding and developments for 2005

  5% "calibration" of *pC* polarimeters within reach

Publications

The list is long:

physics, polarimetry, target, technical contributions to various conferences

Expect several physics publications on spin effects at low t, technical publications on polarimetry, target design and performance, etc.

Spin Symposia 2000, 2002 Jinnouchi, Huang, Bravar, Kurita …
PST 2001 Makdisi on polarimetry

2003
CIPANP 2003 Bravar on the pC CNI and JET
PST 2003 Zelenski on the polarized jet target
CCP 2003 Bravar, Jinnouchi
Dubna 2003 Zelenski, Bravar, Jinnouchi

2004 (planned)
JPS Jinnouchi on the pC CNI polarimeters, Okada on the JET
Diffraction 2004 Bravar
SPIN 2004 Wise, Nass, Zelenski on the JET
Okada on the A_N pp elastic scattering
Jinnouchi on the pC CNI
Svirida on the DAQ systems
APS Haeberli invited talk on the JET